Early Student Support for the Study of Inertial Motions in the Arctic Ocean

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Grant Number: N00014-11-1-0454

LONG-TERM GOALS

The decreasing trend in minimum Arctic Ocean sea-ice extent has been a topic of concern with far reaching effects. At least seasonally, there are good reasons to believe that the Arctic Ocean will become a more dynamically active ocean, with larger surface waves, stronger lateral fronts, and more intense internal wave activity. Particularly in the marginal ice zone, the processes controlling the response of the ocean to wind forcing span a wide range of spatial and temporal scales. In this project, we use a combination of existing instruments and simple models to study the internal wave field in the Arctic Ocean, and the feedback processes between internal wave energy and stratification.

OBJECTIVES

This project supports Ms. Hayley Dosser, a graduate student in the University of Washington Oceanography program. Her work involves a combination of the analysis of existing observational data and numerical modeling to quantify internal wave energy and propagation in the Arctic Ocean. The relationships between the internal wave field and the atmospheric and tidal forcing, as well as with the ice cover, are being investigated. Internal near-inertial waves are associated with vertical isopycnal displacements and vertical shear, and, as in low latitudes, can potentially break and significantly contribute to mixing the water column. As the near-inertial waves are propagating downward in the Canada Basin, they encounter strong upper stratification of the upper halocline (50-200m), and the thermohaline staircase at the top of the Atlantic Water (200-400 m). A goal of Ms. Dosser's thesis is to investigate the interactions between the complex step-like stratification and the waves. Spatial and temporal variability of the inertial wave field are therefore reflected in an inhomogeneous distribution of vertical diffusivity. This directly impacts how temperature, salinity, stratification, and other properties (tracers, nutrients, etc.) evolve in the upper Arctic Ocean (Rainville et al. 2011).

APPROACH

Dosser's project focuses on analyzing the salinity and temperature profiles from the drifting Ice-Tethered Profilers (ITPs) in the Beaufort Gyre region to quantify the near-inertial internal wave field in the Canada Basin. Previous observations of internal waves in the Arctic, typically from ships or ice camps, have been spatially and temporally limited, lacking year-round or multi-year time series. The

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE **30 SEP 2014**	2. REPORT TYPE	3. DATES COVERED **00-00-2014 to 00-00-2014**
4. TITLE AND SUBTITLE **Early Student Support for the Study of Inertial Motions in the Arctic Ocean**		5a. CONTRACT NUMBER 5b. GRANT NUMBER 5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)		5d. PROJECT NUMBER 5e. TASK NUMBER 5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **University of Washington,Applied Physics Laboratory,1013 NE 40th Street,Seattle,WA,98105**		8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)		10. SPONSOR/MONITOR'S ACRONYM(S) 11. SPONSOR/MONITOR'S REPORT NUMBER(S)
12. DISTRIBUTION/AVAILABILITY STATEMENT **Approved for public release; distribution unlimited**		
13. SUPPLEMENTARY NOTES		
14. ABSTRACT		
15. SUBJECT TERMS		

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**Same as Report (SAR)**	**8**	

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std Z39-18

ITPs have collected year-round time series for the last decade, potentially providing an excellent record of the spatial and temporal evolution of internal waves in the region in the upper 750 m of the water column.

WORK COMPLETED

Initially, data from 3 different Ice-Tethered Profilers drifting in the Beaufort Gyre region of the Canada Basin from Fall 2006 to Fall 2007 were used to characterize and quantify the regional near-inertial internal wave field over one year. Work has since been extended to all the processed ITP data available on the WHOI website, from Fall 2005 to Fall 2012 (Figure 1).

Due to poor time resolution and irregular sampling, near-inertial frequency signals are only marginally resolved by ITPs. The initial part of this project demonstrates that by using careful fitting of ideal sinusoidal waves to the measured isopycnal displacements, estimates of the slowly varying amplitude of the inertial wave field can be obtained (Figure 2). Importantly, an error analysis was also carried out and the associated uncertainty due to the poor sampling and possible aliasing of the internal wave continuum was estimated. More details on the technique and initial results can be found in Dosser et al. (2013).

As an example, internal wave amplitudes estimated from ITP6 for an entire year (2006-2007) are shown in Figure 3. There is significant wave activity at all depths, but particularly just below the Atlantic Water maximum (near 400m) and very near the surface. Periods of high amplitude waves are observed every few weeks, and are distributed fairly evenly over all latitudes and longitudes traversed by the ITP (not shown). There is a significant seasonal cycle associated with the scaled vertical displacement amplitude of the waves at all depths.

The waves are predominantly caused by ice motion resulting from surface wind forcing, but ice is playing a dominant role in mediating this interaction (Figure 4). On timescales of days to weeks, fluctuations in wave energy are connected to both increased surface wind forcing and decreased sea-ice cover, with a weak correlation between wind stress and wave amplitude. On a seasonal timescale, decreased sea ice around the ITP during summer is linked to increased wave energy. Thick winter ice may prevent momentum transfer from winter storms to the ocean, damping wave motion and resulting in a mismatch between wind forcing and the wave response. During summer, thin, patchy ice may allow more direct wind forcing of the ocean surface mixed layer, and increase near-inertial wave generation.

Recently, we have started to process the raw ITP data here at APL, applying similar corrections as those documented in Krishfield et al. (2006). This allows us to access data from all ITPs that have been deployed, to the present day.

RESULTS

This work demonstrates that it is possible use the ITP dataset to extract and quantify the near-inertial internal wave field at all depths, including in regions of complex stratification such as the double-diffusive staircase found in the Canada Basin. We see a clear relationship between the wind forcing and the internal wave energy in the water column.

Ms. Dosser is at the beginning of her 5th year in the University of Washington graduate program, expected to graduate within the next year. She is currently analyzing the entire ITP dataset that has been collected in the Canada Basin – providing a 10-year time series of near-inertial energy in the Arctic in a time of extreme transitions.

The broad spatial coverage and continuous time series of observations allow for a careful investigation of changes in internal wave energy during a decade when sea-ice extent and thickness decreased dramatically. Near-inertial internal waves are generally most energetic in summer during sea-ice retreat, with a second peak in energy in early winter during the period of maximum wind velocity. This seasonal variability matches the seasonal cycle in 'wind factor', which relates sea-ice drift velocity to wind velocity (Figure 5). The wind factor varies with sea-ice extent, in a similar manner to the internal wave energy. An increasing inter-annual trend in summer near-inertial wave energy is found for the upper ocean, mirroring the pronounced sea-ice decline in the summer months. Following the 2007 sea-ice minimum, the overall variability in the internal wave field increased significantly, with a wider range of wave amplitudes observed in both summer and winter. This is linked to an overall increase in the wind factor, and may indicate a shift in air-ice-ocean dynamics in the Arctic.

IMPACT/APPLICATIONS

The analysis of all ITPs deployed in the Canada Basin will lead to a multi-year, regional climatology of the inertial wave field. Since all the ITPs are anchored in multi-year ice floes, the inertial wave field will be that of an (at least marginally) ice-covered ocean. The general goal of this work is to undertand the seasonality of the current internal wave field, and the coupling between the atmosthere, the ice, and the ocean. Such knolwedge is critical to accurately model the upper Arctic Ocean and predict the response of the Arctic Ocean to the increased sesonality observed in recent years.

RELATED PROJECTS

The work conducted by Ms. Dosser as part of this award is closely related to the ONR Arctic DRI on the Emerging Dynamics of the Marginal Ice Zone. As part of the MIZ DRI, Craig Lee and Luc Rainville deployed 4 Seagliders in the Arctic in summer 2014, extensively sampling the region between the full ice cover and open water. The glider observations will allow us to compare and constrast the internal wave field across a range of ice conditions, and understand how (and when) the ITP data - always under ice and tethered to an ice floe, by design - are representative of the dynamics in the entire basin.

REFERENCES

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Rainville, L., C.M. Lee, and R.A. Woodgate, 2011. Impact of Wind-Driven Mixing in the Arctic Ocean, *Oceanography Magazine,* 24(3):136–145.

PUBLICATIONS

Dosser, H. V., L. Rainville, and J. M. Toole. 2014. Near-inertial internal wave field in the Canada Basin from Ice-Tethered Profilers.. *J. Phys. Oceanogr.*, **44**, 413–426. doi: http://dx.doi.org/10.1175/JPO-D-13-0117.1

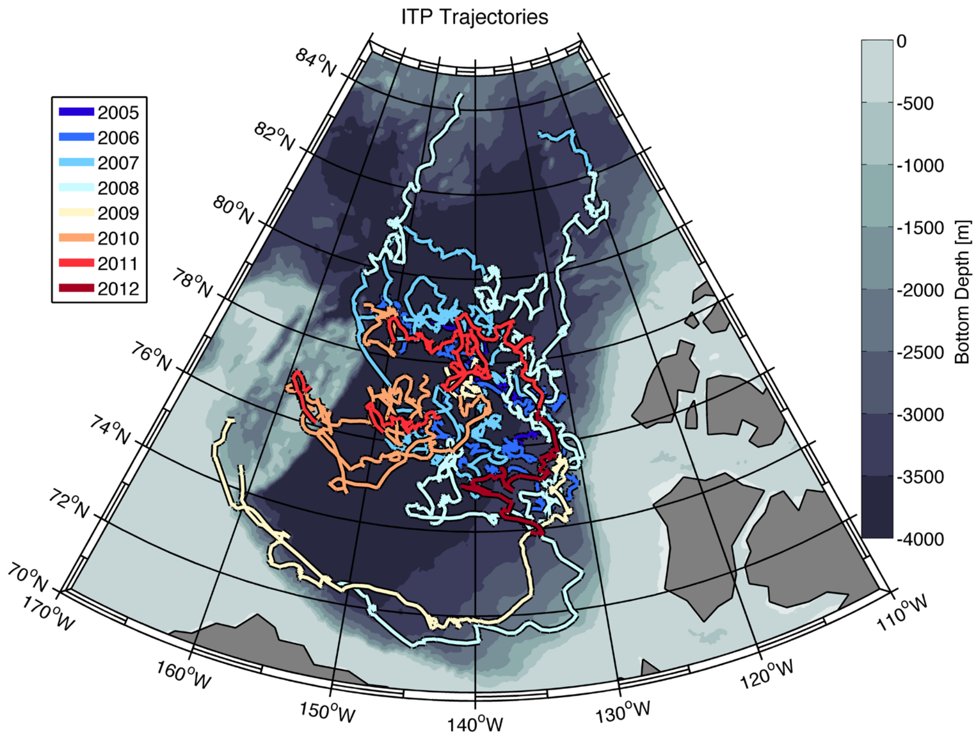

Figure 1: Trajectories all ITPs with processed data available from Fall 2005 to Fall2012 in the Beaufort Gyre region (inset) of the Canada Basin. Colours correspond to different years. Gray contours show bathymetry.

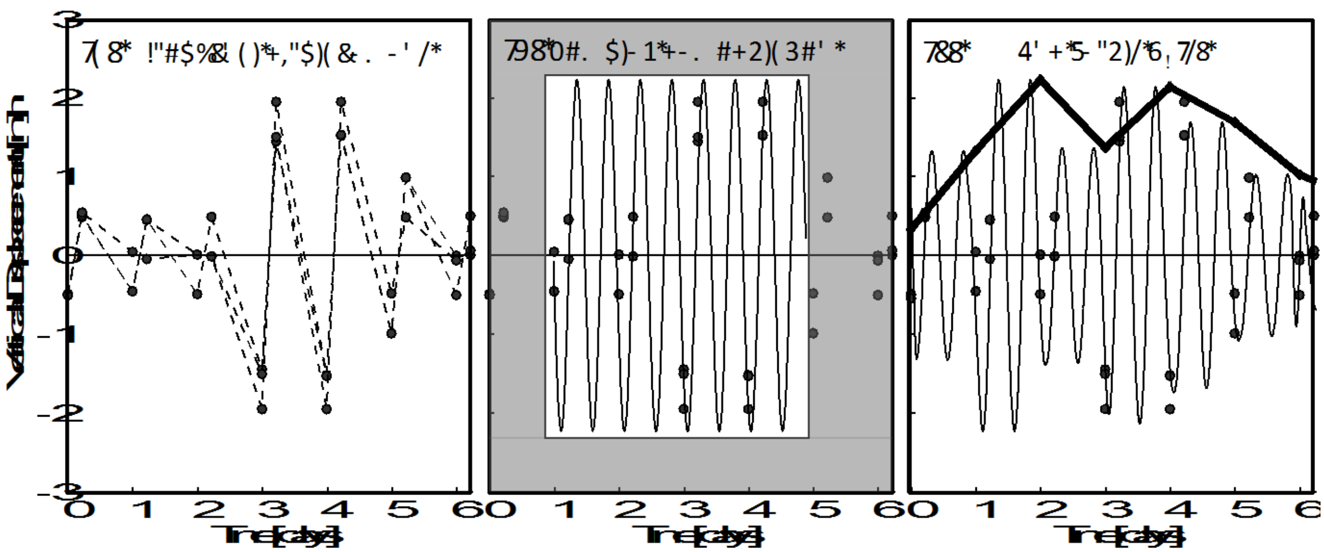

Figure 2: (a) Data: Vertical displacements for isopycnals in a 6-m depth range with the low-frequency signal removed. (b) Method: A harmonic least-squares fit to each window of data gives the amplitude and phase of the ideal cosine (thin black line) that best explains the variance in the data. (c) Result: The complex demodulation procedure produces a slowly varying wave amplitude (thick black line) and phase (not shown) corresponding to a near-inertial wave (thin black line).

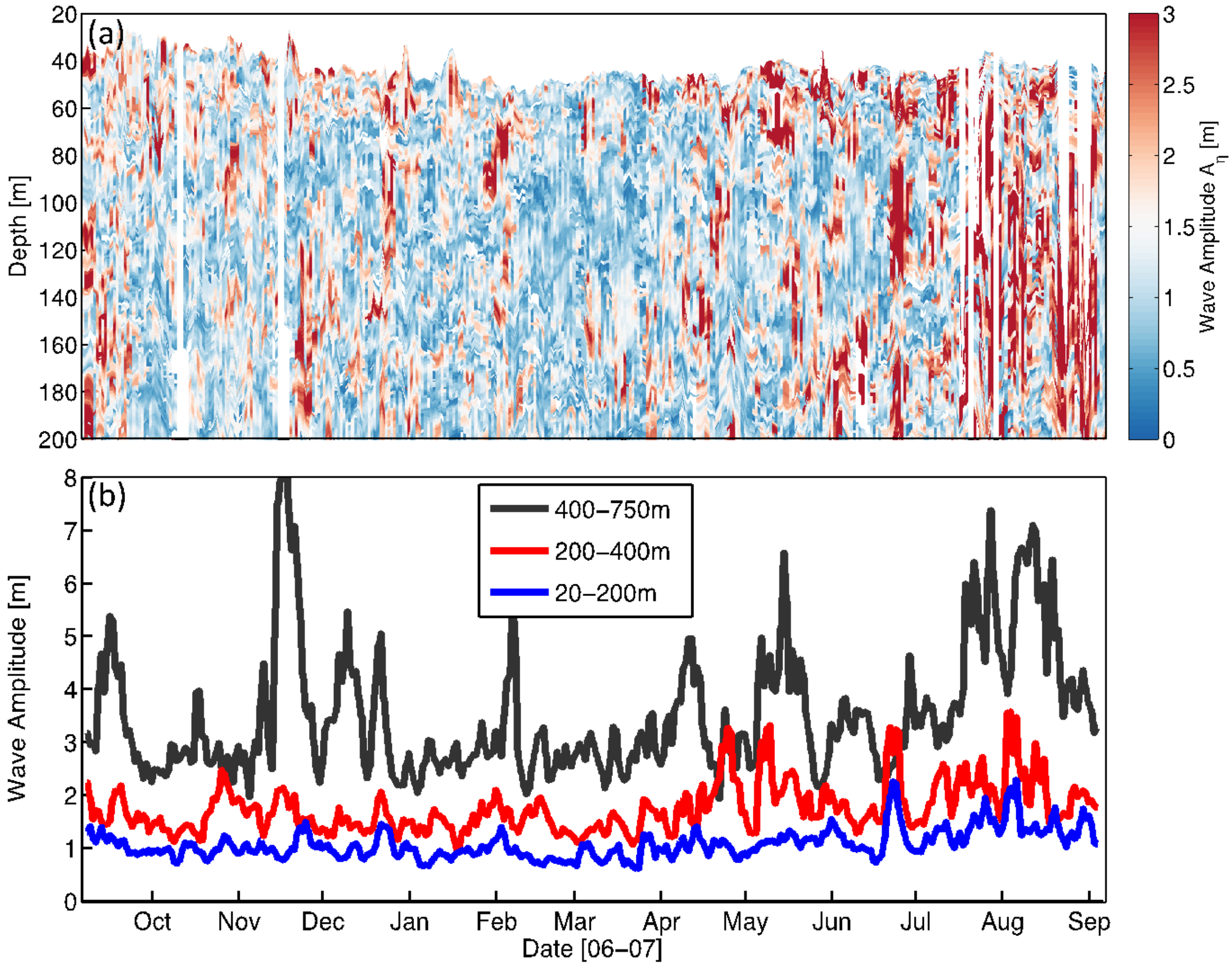

Figure 3: (a) Vertical displacement wave amplitude field for one full year of data from ITP 6, over the top 200 m of the water column. Waves with larger vertical displacements are red. Gaps are regions without data or flagged as estimated with low confidence. (b) Depth-averaged vertical displacement wave amplitude for the top 200 m (blue line), the double-diffusive staircase region from 200-400 m (red line), and the lower water column from 400-750 m (grey line).

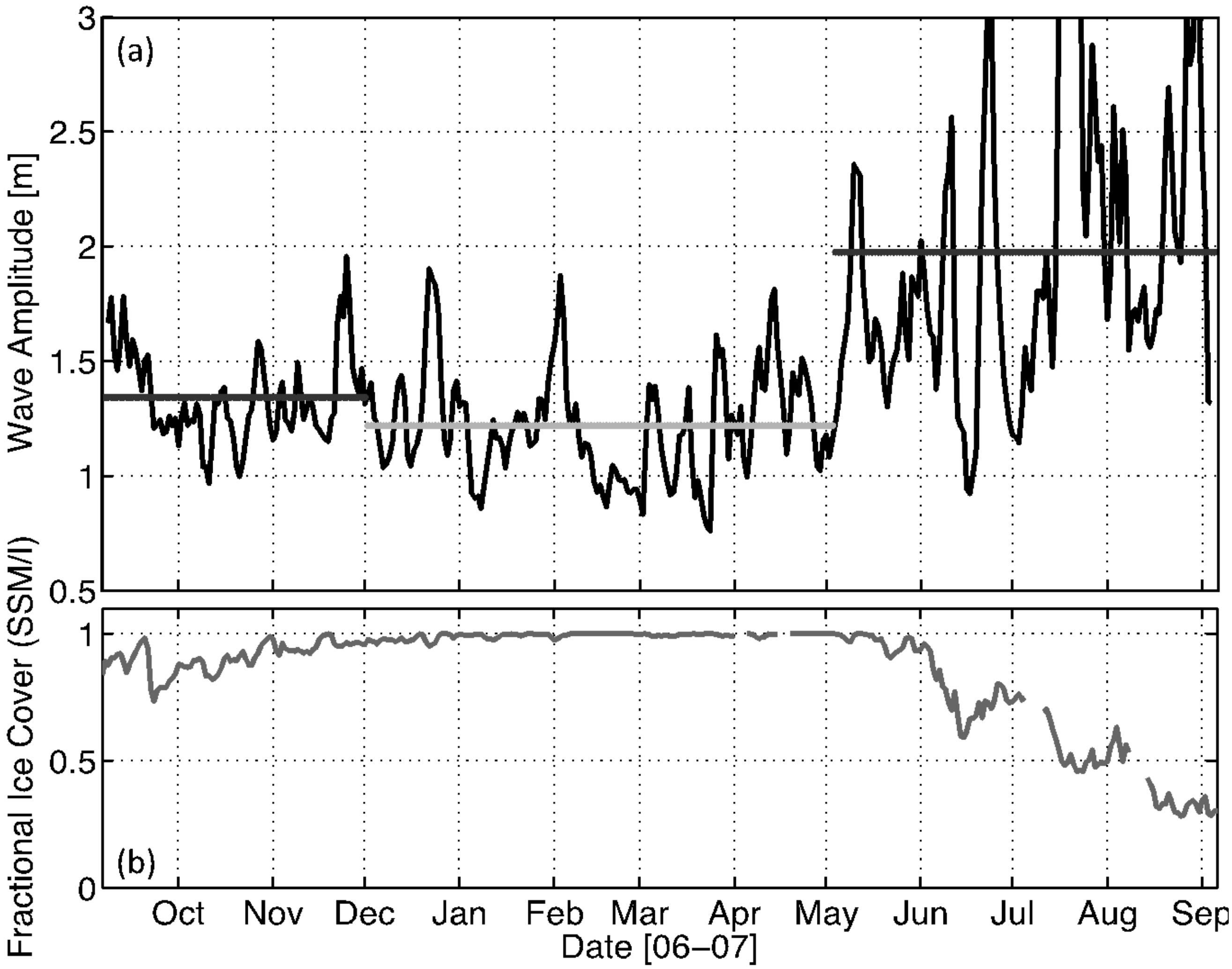

Figure 4: (a) Daily WKB-scaled vertical displacement wave amplitude from ITP 6, depth-averaged over the top 200 m. The dark and light grey lines show the mean wave amplitude during periods of <100% sea-ice cover and 100% sea-ice cover, respectively. (b) The fractional sea-ice cover around the ITP over the course of the year, derived from daily SSM/I ice concentration satellite data.

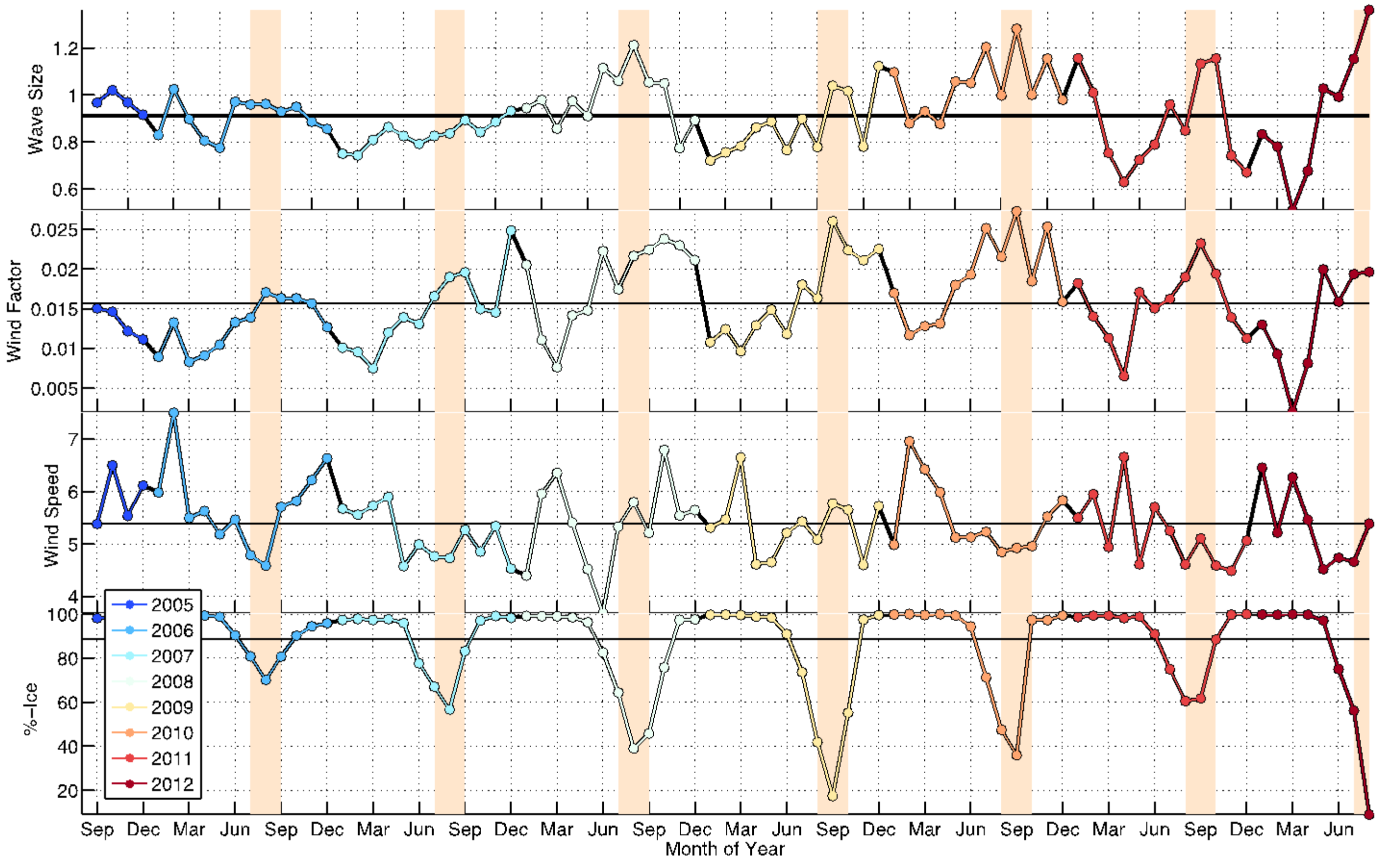

Figure 5: Interannual variations in seasonal cycle from Fall 2005 to Fall 2012. Data is binned monthly and coloured by calendar year. From top to bottom, fields shown are: near-inertial internal wave vertical displacement amplitude, wind factor, wind speed, and percent sea-ice. Tan vertical bars indicate periods of minimum sea-ice extent in summer. Horizontal black lines show the overall time series average for each field.